

## **REMARKS**

Applicants respectfully request reconsideration of the present application in view of the foregoing amendments and in view of the reasons that follow.

Claims 1, 5, 12 and 16-18 are requested to be cancelled without prejudice or disclaimer.

Claims 2-4, 6, 9-11 and 13-15 are currently being amended.

Claims 19-21 are being added.

This amendment adds, changes and deletes claims in this application. A detailed listing of all claims that are, or were, in the application, irrespective of whether the claim(s) remain under examination in the application, is presented, with an appropriate defined status identifier.

After amending the claims as set forth above, claims 2-4, 6-11 and 13-21 are now pending in this application.

### ***Drawings***

The drawings were objected to. Specifically, the Office Action indicated that the low pass filter must be shown or the feature canceled from the claims. Applicants respectfully traverse this objection. The low pass filter in the claims is a mathematical function, not a structure, and as such need not be illustrated in the drawings. Moreover, at least Figure 5 illustrates “low pass filtering” in step S50.

### ***Disclosure***

Paragraph 4 on page 3 of the Office Action stated “Applicant is reminded to use consistent language throughout the disclosure in order to facilitate finding support for the recited limitations, as well as to provide proper antecedence for all claim limitations,” and listed examples a) through d). With respect to a), the claims have been amended to eliminate the acronym “SOC” after “charge rate.” Applicants note that the present specification equates the charge rate with SOC. The claims have been amended to address the issue raised with

respect to b). With respect to c), applicants submit that the recitation in claim 3 of 1/G1(s) as a “transfer function” is consistent with referring to 1/G1(s) as being a low pass filter or having low pass filter characteristics. With respect to d), applicants note that upper case “K” is used for internal resistance while lower case “k” is used for time. Thus, different symbols are used to represent internal resistance and time, and no confusion should result therefrom.

***Claim objections***

The claims were objected to for informalities. The claims have been amended to address the issues raised in the Office Action, and applicants submit that the objections have been overcome.

***Allowable subject matter***

Applicants appreciate the indication that claims 4-11 and 15 contain allowable subject matter.

***Rejections under 35 U.S.C. § 103***

Claims 1-3, 12-14, and 16-18 were rejected under 35 U.S.C. § 103(a) as being unpatentable over “RESEARCH AND DEVELOPMENT OF THE MODEL-BASED BATTERY STATE OF CHARGE INDICATOR” to Torikai et al (Torikai). Claims 16-18 were rejected under 35 U.S.C. § 103(a) as being unpatentable over “MODEL-BASED PREDICTIVE DIAGNOSIS FOR ELECTROCHEMICAL ENERGY SOURCES” to Kozlowski et al (Kozlowski). These rejections are moot with respect to claims 1, 12 and 16-18, which have been canceled. Insofar as these rejections can be applied to the claims as amended, applicants respectfully traverse for at least the following reasons.

Claim 2 has been amended to be in independent form. In claim 2, equation (2) is substituted into battery model equation (1) to obtain equation (4), which does not include any offset term  $V_0$ . Thus, equation (1) can be converted into a product-and-addition equation, equation (4), between a measurable terminal voltage V, current I, and a parameter. This product-and-addition equation provides advantages in processing. Specifically, this allows an adaptive digital filter equation to be directly applied in a continuous time series. As a result, parameters including parameter h can be estimated in a batch processing manner. Open-

circuit voltage  $V_0$  may then be obtained using  $h$  among the batch-estimated parameters. Therefore, the charge rate is accurately estimated from “open-circuit voltage  $V_0$ ” and a predetermined relationship between the open-circuit voltage and the charge rate of the secondary battery.

In a similar fashion to independent claim 2, in independent claim 3, equation (2) is substituted into battery model equation (1) to obtain equation (4), which does not include an offset term  $V_0$ . Thus equation (1) can be converted into the product-and-addition equation, equation (4), between a measurable terminal voltage  $V$ , current  $I$  and a parameter. In a similar fashion to claim 2, in claim 3, this product-and-addition equation provides advantages in processing. Specifically, this allows an adaptive digital filter equation to be directly applied in a continuous time series. As a result, parameters  $A(s)$ ,  $B(s)$  and  $C(s)$  can be estimated, which are substituted into equation (5) of claim 3, which does not include an integration term of estimated parameters. Open-circuit voltage  $V_0$  may thus be obtained without effect of integration error. Therefore, the charge rate is accurately estimated from “open-circuit voltage  $V_0$ ” and a predetermined relationship between the open-circuit voltage and the charge rate of the secondary battery.

Torikai discloses that SOC is estimated by battery model equation (1) expressed with terminal voltage  $V$ , current  $I$  and SOC,  $\theta$ . In contrast to claim 2, however, the battery model equation is not a product-and-addition equation between a measurable terminal voltage  $V$ , current  $I$ , and a parameter, as equation (2) of Torikai shows. As can be seen, the right hand side of equation (2) of Torikai is not a product-and-addition equation between current  $I$  and a parameter. Thus, equation (2) cannot be easily applied to an adaptive digital filter formula, in contrast to the equations of claims 2 or 3.

Claims 13 and 14 are method claims corresponding respectively to claims 2 and 3, and are patentable for analogous reasons.

The dependent claims are patentable for at least the same reasons as their respective independent claims, as well as for further patentable features recited therein.

New dependent claims 20 and 21 have been added, and are likewise believed to be patentable.

The dependent claims are patentable for at least the same reasons as their respective independent claims, as well as for further patentable features recited therein.

Applicants believe that the present application is now in condition for allowance. Favorable reconsideration of the application as amended is respectfully requested.

The Examiner is invited to contact the undersigned by telephone if it is felt that a telephone interview would advance the prosecution of the present application.

The Commissioner is hereby authorized to charge any additional fees which may be required regarding this application under 37 C.F.R. §§ 1.16-1.17, or credit any overpayment, to Deposit Account No. 19-0741. Should no proper payment be enclosed herewith, as by a check being in the wrong amount, unsigned, post-dated, otherwise improper or informal or even entirely missing, the Commissioner is authorized to charge the unpaid amount to Deposit Account No. 19-0741. If any extensions of time are needed for timely acceptance of papers submitted herewith, Applicant hereby petitions for such extension under 37 C.F.R. §1.136 and authorizes payment of any such extensions fees to Deposit Account No. 19-0741.

Respectfully submitted,

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**APPARATUS AND METHOD FOR ESTIMATING CHARGE RATE OF  
SECONDARY CELL**

**BACKGROUND OF THE INVENTION:**

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**Field of the invention**

[0001] The present invention relates to apparatus and method for estimating a charge rate (abbreviated 10 as SOC) of a secondary cell.

**Description of the related art**

[0002] Japanese Patent Application First Publications No. 2000-323183 published on November 24, 15 2000 No. 2000-268886 published on September 29, 2000, and a Japanese Paper titled "Estimation of Open Voltage and Residual Values for Pb Battery by Adaptive Digital Filter" announced by a Japanese Electrical Engineering Society (T.IEEE Japan), Volume 20 112-C, No. 4, published on 1992 exemplify previously proposed SOC estimating apparatus for the secondary cell. That is to say, since the charge rate (or called State Of Charge, i.e., SOC) of the secondary 25 cell has a correlation to an open-circuit voltage  $V_0$  (cell terminal voltage when its power supply of the cell is turned off, also called electromotive force or open voltage), the charge rate can be estimated when open voltage  $V_0$  is obtained. However, a considerable time is needed until the terminal 30 voltage is stabilized after the power supply is turned off (charge-and-discharge is ended). Hence, a predetermined time duration is needed from a time at which the charge-and-discharge is ended to determine

an accurate open-circuit voltage  $V_0$ . Therefore, since immediately after or during the charge/discharge time or charge-and-discharge, it is impossible to determine an accurate open-circuit voltage and the  
5 charge rate cannot be obtained using the above-described method. Nevertheless, to determine the open-circuit voltage  $V_0$ , the open-circuit voltage  $V_0$  is estimated using a method disclosed in the above-described Japanese Patent Application First  
10 Publication No. 2000-323183.

**SUMMARY OF THE INVENTION:**

[0003] However, in the above-described method disclosed in the Japanese Patent Application  
15 Publication No. 2000-323183, open-circuit voltage  $V_0$  is calculated from a non-recursive (non-regression type) cell model (a model whose output value is determined only from a present value and past value of an input value) whose characteristic is wholly  
20 different from a physical characteristic of the cell for which an adaptive digital filter (sequential type model parameter identification algorithm) is used. The charge rate (SOC) is used from this value. Hence, in a case where this method is applied to the actual  
25 cell characteristic (input: current, output: voltage), according to the cell characteristic, an estimation calculation is wholly converged or does not converge to a real value. Hence, it is difficult to estimate the charge rate (SOC) accurately.  
30 [0004] It is, hence, an object of the present invention to provide apparatus and method for estimating accurately the charge rate (SOC) for the

secondary cell and accurately estimating other parameters related to the charge rate (SOC).

[0005] According to one aspect of the present invention, there is provided a charge rate estimating apparatus for a secondary cell, comprising: a current detecting section capable of measuring a current flowing through the secondary cell; a terminal voltage detecting section capable of measuring a voltage across terminals of the secondary cell; a parameter estimating section that calculates an adaptive digital filtering using a cell model in a continuous time series shown in an equation (1) and estimates all ~~of~~-parameters at one time, the parameters corresponding to an open-circuit voltage  $V_0$ , which is an offset term of the equation, (1) and coefficients of  $A(s)$ ,  $B(s)$ , and  $C(s)$ , which are transient terms; and a charge rate estimating section that estimates the charge rate from a previously derived relationship between ~~a previously derived an~~ open-circuit voltage and a charge rate of the secondary cell and the open-circuit voltage  $V_0$  and the charge rate SOC using the open-circuit voltage  $V_0$ ,

$$V = \frac{B(s)}{A(s)} \bullet I + \frac{1}{C(s)} \bullet V_0 \quad \text{--- (1), wherein } s \text{ denotes a}$$

Laplace transform operator,  $A(s)$ ,  $B(s)$ , and  $C(s)$  denote poly-nominal functions of  $s$ .

[0006] According to another aspect of the present invention, there is provided a charge rate estimating method for a secondary cell, comprising: measuring a current flowing through the secondary cell; measuring a voltage across terminals of the secondary cell; calculating an adaptive digital

filtering using a cell model in a continuous time series shown in an equation (1); estimating all of parameters at one time, the parameters corresponding to an open-circuit voltage  $V_0$ , which is an offset term of the equation (1), and coefficients of  $A(s)$ ,  $B(s)$ , and  $C(s)$ , which are transient terms; and estimating the charge rate from a previously derived relationship between an open-circuit voltage and a charge rate of secondary cell, and the a previously  
 5 derived open-circuit voltage  $V_0$  and the charge rate  
 10 SOC using the open-circuit voltage  $V_0$ ,

$$V = \frac{B(s)}{A(s)} \bullet I + \frac{1}{C(s)} \bullet V_0 \quad \text{--- (1), wherein } s \text{ denotes a}$$

Laplace transform operator,  $A(s)$ ,  $B(s)$ , and  $C(s)$  denote poly-nominal functions of  $s$ .

15 [0007] According to a still another object of the present invention, there is provided a charge rate estimating method for a secondary cell, comprising: measuring a current  $I(k)$  flowing through the secondary cell; measuring a terminal voltage  $V(k)$  across the secondary cell; storing the terminal voltage  $V(k)$  when a current is zeroed as an initial value of the terminal voltage  $\Delta V(k) = V(k) - V_{\text{ini}}$ ; determining instantaneous current values  $I_0(k)$ ,  $I_1(k)$ , and  $I_3(k)$  and instantaneous terminal voltages  $V_1(k)$ ,  
 20  $V_2(k)$ , and  $V_3(k)$  from an equation (19),  
 25

$$I_0 = \frac{1}{G_1(s)} \bullet I,$$

$$I_1 = \frac{s}{G_1(s)} \bullet I, \quad V_1 = \frac{s}{G_1(s)} \bullet V,$$

$$I_2 = \frac{s^2}{G_1(s)} \bullet I, \quad V_2 = \frac{s^2}{G_1(s)} \bullet V,$$

$$I_3 = \frac{s^3}{G_1(s)} \bullet I, \quad V_3 = \frac{s^3}{G_1(s)} \bullet V, \quad \text{and}$$

$$\frac{1}{G_1(s)} = \frac{1}{(p_1 \bullet s + 1)^3} \quad \text{--- (19), wherein } p_1 \text{ denotes a}$$

constant determining a responsive characteristic of  
 $G_1(s)$ ; substituting the instantaneous current values  
5     $I_0(k)$ ,  $I_1(k)$ ,  $I_2(k)$ , and  $I_3(k)$  and the instantaneous  
terminal voltages  $V_1(k)$ ,  $V_2(k)$ , and  $V_3(k)$  into an  
equation (18),

$$\gamma(k) = \frac{\lambda_3(k)}{1 + \lambda_3(k) \bullet \omega^T(k) \bullet P(k-1) \bullet \omega(k)}$$

$$\theta(k) = \theta(k-1) - \gamma(k) \bullet P(k-1) \bullet \omega(k) \bullet [\omega^T(k) \bullet \theta(k-1) - y(k)]$$

$$10 \quad P(k) = \frac{1}{\lambda_1(k)} \left\{ P(k-1) - \frac{\lambda_3(k) \bullet P(k-1) \bullet \omega(k) \bullet \omega^T(k) \bullet P(k-1)}{1 + \lambda_3(k) \bullet \omega^T(k) \bullet P(k-1) \bullet \omega(k)} \right\} = \frac{P'(k)}{\lambda_1(k)}$$

$$\lambda_1(k) = \begin{cases} \frac{\text{trace}\{P'(k)\}}{\gamma_U} : \lambda_1 \leq \frac{\text{trace}\{P'(k)\}}{\gamma_U} \\ \times \lambda_1 : \frac{\text{trace}\{P'(k)\}}{\gamma_U} \leq \lambda_1 \leq \frac{\text{trace}\{P'(k)\}}{\gamma_L} \\ \times \frac{\text{trace}\{P'(k)\}}{\gamma_L} : \frac{\text{trace}\{P'(k)\}}{\gamma_L} \leq \lambda_1 \end{cases}$$

15

$$\text{----- (18),}$$

wherein  $\theta(k)$  denotes a parameter estimated value at a time point of  $k$  ( $k = 0, 1, 2, 3 \dots$ ),  $\lambda_1$ ,  $\lambda_3(k)$ ,  $\gamma_U$ , and  $\gamma_L$  denote initial set value,  $b < \lambda_1 < 1$ ,  $0 < \lambda_3(k) < \infty$ .  $P(0)$  is a sufficiently large value,  $\theta(0)$  provides an initial value which is non-zero but very sufficiently small value,  $\text{trace}\{P\}$  means a trace of matrix  $P$ , wherein  $y(k) = V_1(k)$

$$\omega^T(k) = [V_3(k) \quad V_2(k) \quad I_3(k) \quad I_2(k) \quad I_1(k) \\ I_0(k)]$$

$$\theta(k) = \begin{bmatrix} -a(k) \\ -b(k) \\ c(k) \\ d(k) \\ e(k) \\ f(k) \end{bmatrix} \quad \text{---- (20);}$$

substituting a, b, c, d, e, and f in the parameter  
 5 estimated value  $\theta(k)$  into and equation (22) to calculate  $V_0'$  which is an alternate of  $V_0$  which corresponds to a variation  $\Delta V_0(k)$  of the open-circuit voltage estimated value from a time at which the estimated calculation start is carried out;

10  $V_0' = \frac{(T_1 \cdot s + 1)}{G_2(s)} \cdot V_0 = a \cdot V_6 + b \cdot V_5 + V_4 - c \cdot I_6 - d \cdot I_5 - e \cdot I_4 \quad \text{--- (22);}$  and calculating an open-circuit voltage estimated value  $V_0(k)$  according the variation  $\Delta V_0(k)$  of the open-circuit voltage estimated value and the terminal voltage initial value  $V_{\text{ini}}$ .

15 **[0008]** This summary of the invention does not necessarily describe all necessary features so that the invention may also be a sub-combination of these described features.

20 **BRIEF DESCRIPTION OF THE DRAWINGS:**

**[0009]** Fig. 1 is a functional block diagram of an apparatus for estimating a charge rate (SOC) of a secondary cell in a preferred embodiment according to the present invention.

25 **[0010]** Fig. 2 is a specific circuit block diagram of the apparatus for estimating the charge rate (SOC)

of the secondary cell in the preferred embodiment according to the present invention.

[0011] Fig. 3 is a model view representing an equivalent circuit model of the secondary cell.

5 [0012] Fig. 4 is a correlation map representing a correlation between an open-circuit voltage and a charge rate (SOC).

10 [0013] Fig. 5 is an operational flowchart for explaining an operation of a microcomputer of a battery controller of the charge rate estimating apparatus in the first preferred embodiment shown in Fig. 1.

15 [0014] Figs. 6A, 6B, 6C, 6D, 6E, 6F, 6G, 6H and 6I are characteristic graphs representing results of simulations of current, voltages, and various parameters in a case of the charge rate estimating apparatus in the embodiment shown in Fig. 1

**DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS:**

20 [0015] Reference will hereinafter be made to the drawings in order to facilitate a better understanding of the present invention.

25 [0016] Fig. 1 shows a functional block diagram of charge rate estimating apparatus in a first preferred embodiment according to the present invention. In Fig. 1, a reference numeral 1 denotes a parameter estimating section based on a cell model with an open-circuit voltage  $V_0(k)$  as an offset term. In addition, a reference numeral 2 denotes an open-circuit voltage calculating section to calculate open-circuit voltage  $V_0(k)$ , and a reference numeral 30 3 denotes a charge rate estimating section that calculate the charge rate from the open-circuit

voltage. In addition, a reference numeral 4 denotes a current I measuring block to detect current  $I(k)$  which is charged and discharged into and from the cell, and a reference numeral 5 denotes a terminal voltage of the cell to measure the terminal voltage  $V(k)$ .

[0017] Fig. 2 shows a block diagram representing a specific structure of the charge rate estimating apparatus in the first embodiment. In this embodiment, 10 a load such as a motor is driven with the secondary cell and the charge rate estimating apparatus is mounted in a system to charge the secondary cell with a regenerative power of the motor (load). In Fig. 2, a reference numeral 10 denotes a secondary cell 15 (simply called, a cell), a reference numeral 20 denotes a load such as a DC motor, a reference numeral 30 denotes a battery controller (electronic control unit) to estimate the charge rate (charge state) of the cell having a microcomputer including a 20 ROM (Read Only Memory), a RAM (Random Access Memory), a CPU (central Processing Unit), and Input/Output Interface and other electronic circuits. A reference numeral 40 denotes a current meter to detect a current which is charged into or discharged from the 25 cell, a reference numeral 50 denotes a voltage meter to detect the terminal voltage of the cell, a reference numeral 60 denotes a temperature meter to detect a temperature of the cell. These meters are connected to battery controller 30. Battery controller 30 corresponds to parts of parameter estimating section 1, an open-circuit voltage  $V_o(k)$  and a charge rate estimating section 3. Current meter 40 corresponds to current  $I(k)$  measuring

section and voltage meter 50 correspond to terminal voltage  $V(k)$  measuring section 5.

**[0018]** First, a "cell model" used in the first embodiment will be described below. Fig. 3 is an equivalent circuit representing an equivalent circuit model of the secondary cell. The equivalent circuit model of the secondary cell can be represented by the following equation (7) (= equation (6)).

$$10 \quad V = \frac{K \cdot (T_2 \cdot s + 1)}{T_1 \cdot s + 1} \cdot I + \frac{1}{T_3 \cdot s + 1} V_0 \quad --- (7).$$

In equation (7), a model input is a current  $I$  [A] (a positive value represents a charge and a negative value represents a discharge), a model output is a terminal voltage  $V$  [V], an open-circuit voltage is  $V_0$ ,  $K$  denotes an internal resistance,  $T_1$  through  $T_3$  denote time constants ( $T_1 \neq T_2 \neq T_3$ ,  $T_1 \ll T_3$ ) and  $s$  denotes a Laplace transform operator.

**[0019]** In this model based on equation of (7) is a reduction model (first order) in which a positive pole and a negative pole are not specially separated from each other. However, it is possible to represent a charge-discharge characteristic of an actual cell relatively easily. Equation (7), in equation (1) of  $V = B(s)/A(s) \cdot I + 1/C(s) \cdot V_0 \quad --- (1)$ ,  $A(s) = T_1 \cdot s + 1$ ,  $B(s) = K \cdot (T_2 \cdot s + 1)$ ,  $C(s) = T_3 \cdot s + 1$ .

**[0020]** Hereinafter, a deviation from the cell model based on equation (7) to an adaptive digital filter will first be described below. Open-circuit voltage  $V_0$  can be described by an equation (8), supposing that a value of a current  $I$  multiplied with a

variable efficiency of A is integrated from a certain initial state.

$$\text{That is to say, } V_0 = \frac{A}{s} \bullet I \quad \text{--- (8).}$$

It is noted that equation (8) corresponds to  
5 a replacement of h recited in equation (2), viz.,  $V_0 = h/s \bullet I$  with efficiency of A.

**[0021]** If equation (8) is substituted into equation (7), equation (9) is resulted.

$$10 \quad V_0 = \frac{K \bullet (T_2 \bullet s + 1)}{T_1 \bullet s + 1} \bullet I + \frac{1}{T_3 \bullet s + 1} \bullet \frac{A}{s} \bullet I \quad \text{--- (9).}$$

Equation (9) corresponds to equation (3) (V  
~~=  $\left( \frac{B(s)}{A(s)} + \frac{1}{C(s)} \bullet \frac{h}{s} \right) \bullet I - \left( \frac{B(s)}{A(s)} + \frac{1}{C(s)} \bullet \frac{h}{s} \right) \bullet I = \frac{s \bullet B(s) \bullet C(s) + h \bullet A(s)}{s \bullet A(s) \bullet C(s)} \bullet I$~~   
--- (3)). For  $A(s)$ ,  $B(s)$ , and  $C(s)$  in equation (3),  
the following equations are substituted into equation  
15 (9) in the same way as the case of equation (7).

$$A(s) = T_1 \bullet s + 1,$$

$$B(s) = K \bullet (T_2 \bullet s + 1)$$

$C(s) = T_3 \bullet s + 1$ . In other words, equation (3) is a generalized equation and this application to  
20 a first order model is equation (9). If equation (9) is arranged, an equation of (10) is given.

$$\begin{aligned} S \bullet (T_1 \bullet s + 1) (T_3 \bullet s + 1) \bullet V &= K \bullet (T_2 \bullet s + 1) (T_3 \bullet s + 1) s \bullet I + \\ A \bullet (T_1 \bullet s + 1) \bullet I \\ \{T_1 \bullet T_3 \bullet s^3 + (T_1 + T_3) \bullet s^2 + s\} \bullet V &= \{K \bullet T_2 \bullet T_3 \bullet s^3 + K \bullet \\ 25 \quad (T_2 + T_3) \bullet s^2 + (K + A \bullet T_1) \bullet s + A\} \bullet I \\ (a \bullet s^3 + b \bullet s^2 + s) \bullet V &= (c \bullet s^3 + d \bullet s^2 + e \bullet s + f) \bullet I \quad \text{---} \\ (10). \text{ It is noted that, in the last equation of} \\ \text{equation (10), parameters are rewritten as follows:} \end{aligned}$$

$a = T_1 \cdot T_3$ ,  $b = T_1 + T_3$ ,  $c = K \cdot T_2 \cdot T_3$ ,  $d = K \cdot (\underline{T_1} \underline{T_2} + T_3)$ ,  $e = K + A \cdot T_1$ , and  $f = A$  --- (11).

If a stable low pass filter  $G_1(s)$  is introduced into both sides of equation (10) and arranged, the  
5 following equation (12) is given.

$$\frac{1}{G_1(s)} (a \cdot s^3 + b \cdot s^2 + s) \cdot V = \frac{1}{G_1(s)} (c \cdot s^3 + d \cdot s^2 + e \cdot s + f) \cdot I$$

--- (12). In details, in equation (10), on the contrary of equation (7), if  $T_1 \cdot s + 1 = A(s)$ ,  $K \cdot (T_2 \cdot s + 1) = B(s)$ , and  $T_3 \cdot s + 1 = C(s)$  are substituted into equation (10), this is given as:  $s \cdot A(s) \cdot C(s) \cdot V = B(s) \cdot C(s) \cdot s \cdot I + A \cdot A(s) \cdot I$ . This is rearranged as follows:  $s \cdot A(s) \cdot C(s) \cdot V = [B(s) \cdot C(s) \cdot s \cdot [\cdot I]] + A \cdot A(s) \cdot I$  --- (12)'. If, the low pass filter (LPF),  $G_1(s)$  is introduced into both sides of equation (12)', 15 an equation (4) is given.

That is to say,  $\frac{s \cdot A(s) \cdot C(s)}{G_1(s)} \cdot V = \frac{s \cdot B(s) \cdot C(s) + h \cdot A(s)}{s \cdot A(s) \cdot C(s)} \cdot I$  ---

(4). It is noted that  $s$  denotes the Laplace transform operator,  $A(s)$ ,  $B(s)$ , and  $C(s)$  denote a poly-nominal function of  $s$ ,  $h$  denotes a variable, and  $1/G_1(s)$  denotes a transfer function having a low pass filter characteristic. That is to say, equation (4) is the generalized function, equation (12) is the application of equation (4) to the first order model.  
20

25 [0022] Current  $I$  and terminal voltage  $V$  which can actually be measured are processed by means of a low pass filter (LPF) and a band pass filter (BPF) are defined in the following equations (13), provided that  $p_1$  denotes a constant to determine a responsive

characteristic of  $G_1(s)$  and is determined according to a designer's desire.

$$\begin{aligned}
 I_0 &= \frac{1}{G_1(s)} \bullet I \\
 I_1 &= \frac{s}{G_1(s)} \bullet I, & V_1 &= \frac{s}{G_1(s)} \bullet V, \\
 5 \quad I_2 &= \frac{s^2}{G_1(s)} \bullet I, & V_2 &= \frac{s^2}{G_1(s)} \bullet V, \\
 I_3 &= \frac{s^3}{G_1(s)} \bullet I, & V_3 &= \frac{s^3}{G_1(s)} \bullet V, \\
 \frac{1}{G_1(s)} &= \frac{1}{(P_1 \bullet s + 1)^3} & --- (13)
 \end{aligned}$$

If equation (12) is rewritten using the variables shown in equations (13), equations (14) are represented and, if deformed, the following equation (15) is given.

$$\begin{aligned}
 a \bullet V_3 + b \bullet V_2 + V_1 &= c \bullet I_3 + d \bullet I_2 + e \bullet I_1 + \\
 f \bullet I_0 \\
 15 \quad V_1 &= -a \bullet V_3 - b \bullet V_2 + c \bullet I_3 + d \bullet I_2 + e \bullet I_1 + \\
 f \bullet I_0 &--- (14).
 \end{aligned}$$

$$V_1 = [V_3 \quad V_2 \quad I_3 \quad I_2 \quad I_1 \quad I_0] \bullet [[=]] \begin{bmatrix} -a \\ -b \\ c \\ d \\ e \\ f \end{bmatrix} --- (15).$$

Equation (15) is a product-sum equation of measurable values and unknown parameters. Hence, a standard (general) type (equation (16)) of the adaptive digital filter is coincident with equation (15).

It is noted that  $\omega^T$  means a transposed vector in which a row and column of a vector  $\omega$  are mutually exchanged.

5        $y = \omega^T \cdot \theta$  --- (16). It is noted that  $y$ ,  $\omega^T$ , and  $\theta$  can be expressed in the following equation (17) in equation (16) described above.

$$Y = V_1, \quad \omega^T = [V_3 \quad V_2 \quad I_3 \quad I_2 \quad I_1 \quad I_0], \quad \theta = \begin{bmatrix} -a \\ -b \\ c \\ d \\ e \\ f \end{bmatrix} \quad --- (17).$$

Hence, if a signal filter processed for current  $I$  and terminal voltage  $V$  is used in a digital filter  
10 process calculation, unknown parameter vector  $\theta$  can be estimated.

**[0023]**      In this embodiment, " a both-limitation trace gain method is used which improves a logical demerit of a simple " an adaptive digital filter by  
15 means of a least square method " such that once the estimated value is converged, an accurate estimation cannot be made any more even if the parameters are changed. A parameter estimating algorithm to estimate unknown parameter vector  $\theta$  with equation (16) as a prerequisite is as shown in an equation (18). It is noted that the parameter estimated value at a time point of  $k$  is  $\theta(k)$ .

$$\gamma(k) = \frac{\lambda_3(k)}{1 + \lambda_3(k) \cdot \omega^T(k) \cdot P(k-1) \cdot \omega(k)}$$

25       $\theta(k) = \theta(k-1) - \gamma(k) \cdot P(k-1) \cdot \omega(k) \cdot [\omega^T(k) \cdot \theta(k-1) - y(k)]$

$$P(k) = \frac{1}{\lambda_1(k)} \left\{ P(k-1) - \frac{\lambda_3(k) \cdot P(k-1) \cdot \omega(k) \cdot \omega^T(k) \cdot P(k-1)}{1 + \lambda_3(k) \cdot \omega^T(k) \cdot P(k-1) \cdot \omega(k)} \right\} = \frac{P'(k)}{\lambda_1(k)}$$

$$\lambda_1(k) = \begin{cases} \cancel{\frac{\text{trace}\{P'(k)\}}{\gamma_U} : \lambda_1 \leq \frac{\text{trace}\{P'(k)\}}{\gamma_U}} \\ \cancel{\lambda_1 : \frac{\text{trace}\{P'(k)\}}{\gamma_U} \leq \lambda_1 \leq \frac{\text{trace}\{P'(k)\}}{\gamma_L}} \\ \cancel{\frac{\text{trace}\{P'(k)\}}{\gamma_L} : \frac{\text{trace}\{P'(k)\}}{\gamma_L} \leq \lambda_1} \end{cases}$$

5

----- (18).

In equations (18),  $\lambda_1$ ,  $\lambda_3(k)$ ,  $\gamma_u$ , and  $\gamma_L$  denote initial set value,  $0 < \lambda_1 < 1$ ,  $0 < \lambda_3(k) < \infty$ .

10  $P(0)$  is a sufficiently large value,  $\theta(0)$  provides an initial value which is non-zero but very sufficiently small value. In addition,  $\text{trace}\{P\}$  means a trace of matrix  $P$ . As described above, the derivation of the adaptive digital filter from cell model.

**[0024]** Fig. 5 shows an operational flowchart carrying out the microcomputer of battery controller 30. A routine shown in 5 is carried out for each constant period of time  $T_0$ . For example,  $I(k)$  is the present value and  $I(k-1)$  means a one previous value of  $I(k)$ . At a step S10, battery controller 30 measures current  $I(k)$  and  $I(k-1)$  means one previous value of  $I(k)$ . At s-a step S20, battery controller 30 carries out a turn on-and-off determination of an interrupt relay of the secondary cell. That is to say, battery controller 30 performs the on-and-off control of the interrupt relay of the secondary cell. When a relay is turned off (current  $I = 0$ ), the routine goes to a step S30. During the engagement of the relay, the routine goes to a step S40. At step

S30, when the relay is engaged, the routine goes to a step S540. At step S530, battery controller 30 serves to store terminal voltage  $V(k)$  to as an initial value of the terminal voltage  $V_{ini}$ . At a 5 step S40, battery controller 30 calculates a differential value  $\Delta V(k)$  of the terminal voltage.  $\Delta V(k) = V(k) - V_{ini}$ . This is because the initial value of the estimation parameter in the adaptive digital filter is 0 so that the estimation parameter 10 does not converge during the estimation calculation start time. Thus, all of inputs are zeroed. During the input being all zeroed. During the relay interruption, step S30 have been passed and the estimation parameters are remains initial state since 15  $I = 0$  and the estimation parameter remains alive.

**[0025]** At step S50, a low pass filtering or band pass filtering are carried out the current  $I(k)$  and terminal voltage difference value  $\Delta V(k)$  on the basis of equation (13).  $I_0(k)$  through  $I_3(k)$  and  $V_1(k)$  20 through  $V_3(k)$  are calculated from equation (19). In this case, in order to improve an estimation accuracy of the parameter estimation algorithm of equation (18), a responsive characteristic of low pass filter  $G_1(s)$  is set to be slow so as to reduce observation 25 noises. However, if the characteristic is quicker than a response characteristic of the secondary cell (a rough value of time constant  $T_1$  is known), each parameter of the electric cell model cannot accurately be estimated. It is noted that  $p_1$  recited 30 in equation (19) denotes a constant determined according to the responsive characteristic of  $G_1(s)$ .

[0026]  $I_0 = \frac{1}{G_1(s)} \bullet I ,$

 $I_1 = \frac{s}{G_1(s)} \bullet I , \quad V_1 = \frac{s}{G_1(s)} \bullet V ,$ 
 $I_2 = \frac{s^2}{G_1(s)} \bullet I , \quad V_2 = \frac{s^2}{G_1(s)} \bullet V ,$ 
 $I_3 = \frac{s^3}{G_1(s)} \bullet I , \quad V_3 = \frac{s^3}{G_1(s)} \bullet V , \text{ and}$

5  $\frac{1}{G_1(s)} = \frac{1}{(p1 \bullet s + 1)^3}$

----- (19) .

At a step S60,  $I_0(k)$  through  $I_3(k)$  calculated at step S50 and  $V_1(k)$  through  $V_3(k)$  are substituted into equation (18). Then, the parameter estimation 10 algorithm in the adaptive digital filter, viz., equation (18) is executed to calculate parameter estimated value  $\theta(k)$ .  $y(k)$ ,  $\omega^T(k)$ , and  $\theta(k)$  are shown in equation (20).

15  $y(k) = V_1(k)$

 $\omega^T(k) = [V_3(k) \quad V_2(k) \quad I_3(k) \quad I_2(k) \quad I_1(k)$ 
 $I_0(k)]$

$$\theta(k) = \begin{bmatrix} -a(k) \\ -b(k) \\ c(k) \\ d(k) \\ e(k) \\ f(k) \end{bmatrix} \quad ----- (20) .$$

At a step S70, a through e of parameter estimated 20 value  $\theta(k)$  calculated at step S60 are substituted into the following equation (22) in which the above-described cell model equation (7) is deformed to calculate  $V_0'$  which is an alternative to open-circuit

voltage  $V_0$ . Since the variation in open-circuit voltage  $V_0$  is smooth,  $V_0'$  can be used alternatively. It is noted that the derivation herein is a variation  $\Delta V_0(k)$  of the open-circuit voltage from the estimated calculation start time.

[0027] It is noted that an equation of  $[1/C_1(s)]I$  in equation (21) is replaced with an equation (24) corresponds to equation (22). It is also noted that, in the derivation of equation (22),  $K$  in equation (21) is strictly different from  $e$  in equation (21). However, since, physically,  $K \gg A \bullet T_1$ ,  $e$  is approximated to  $K$  ( $e \approx K$ ). Then, each coefficient  $a$  through  $e$  in equation (22) is the contents shown in equation (23).

$$\begin{aligned}
 15 \quad & \frac{1}{T_3 \bullet s + 1} \bullet V_0 = V - \frac{K \bullet (T_2 + s + 1)}{T_1 \bullet s + 1} \bullet I \\
 & (T_1 \bullet s + 1) \bullet V_0 = (T_1 \bullet s + 1) (T_3 \bullet s + 1) V - \\
 & K \bullet (T_2 \bullet s + 1) (T_3 \bullet s + 1) \bullet I \\
 & (T_1 \bullet s + 1) \bullet V_0 = \{T_1 \bullet T_3 \bullet s^2 + (T_1 + T_3) \bullet s + \\
 & 1\} \bullet V \\
 20 \quad & - \{K \bullet T_2 \bullet T_3 \bullet s^2 + K \bullet (T_2 + T_3) \bullet s + K\} \bullet I \\
 & \frac{(T_1 \bullet s + 1)}{G_2} \bullet V_0 = \frac{1}{G_2(s)} (a \bullet s^2 + b \bullet s + K) \bullet I \\
 & \text{--- (21).} \\
 & V' = \frac{(T_1 \bullet s + 1)}{G_2(s)} \bullet V_0 = a \bullet V_6 + b \bullet V_5 + V_4 - c \bullet I_6 - d \bullet I_5 - e \bullet I_4 - \\
 & \text{-- (22).}
 \end{aligned}$$

25

[0028] It is noted that  $a = T_1 \bullet T_3$ ,  $b = T_1 + T_3$ ,  $c = K \bullet (T_2 + T_3)$ ,  $d = K \bullet (T_2 + T_3)$ ,  $e = K + A \bullet T_1 = K$  -- - (23).

$$\begin{aligned}
 [0029] \quad I_4 &= \frac{1}{G_2(s)} \bullet I, \quad V_4 = \frac{1}{G_2(s)} \bullet V, \\
 I_5 &= \frac{s}{G_2(s)} \bullet I, \quad V_5 = \frac{s}{G_2(s)} \bullet V, \\
 \frac{1}{G_2(s)} &= \frac{1}{p_2 \bullet s + 1} \bullet \frac{1}{T_1' \bullet s + 1}, \\
 I_6 &= \frac{s^2}{G_2(s)} \bullet I, \text{ and } V_6 = \frac{s^2}{G_2(s)} \bullet V \quad ---- (24).
 \end{aligned}$$

5 [0030]  $p_2$  recited in equations (24) denote a constant to determine a responsive characteristic of  $G_2(s)$ .  $T_1$  of the cell parameter is known to be several seconds. Hence,  $T_1'$  in equation (24) is set to be approximated value to  $T_1$ . Thereby, since  $(T_1 \bullet s + 1)$  which remains in a numerator of equation (22) can be compensated, the estimation accuracy of open-circuit voltage  $V_0$  can be improved. It is noted that equation (21) corresponds to equation (5). That is to say, equation (21) is derived from  $(T_1 \bullet s + 1) \bullet V_0 = (T_1 \bullet s + 1)(T_3 \bullet s + 1) \bullet V - K \bullet (T_2 \bullet s + 1)(T_3 \bullet s + 1) \bullet (T_3 \bullet s + 1) \bullet I$ . If the following three equations are substituted into the above-described deformation of equation (21).  $T_1 \bullet s + 1 = A(s)$ ,  $K \bullet (T_2 \bullet s + 1) = B(s)$ , and  $T_3 \bullet s + 1 = C(s)$ . That is to say,  $A(s) \bullet V_0 = A(s) \bullet C(s) \bullet V - B(s) \bullet C(s) \bullet I$ . If this is rearranged, this results in  $V_0 = C(s) \bullet V - B(s) \bullet C(s) \bullet I / A(s)$ ,  $V_0 = C(s) \bullet [V - B(s) \bullet I / A(s)]$ . If low pass filter  $G_2(s)$  is introduced into both sides of this equation, this results in equation (5). In details, equation (5) is a generalization equation and the application of equation (5) to the first order model is equation (2).

[0031] At a step S80, battery controller 30 adds the open-circuit voltage initial value, i.e., terminal voltage initial value  $V_{\text{ini}}$  to a variation  $\Delta V_0(k)$  of open-circuit voltage  $V_0$  so as to obtain 5 open-circuit voltage estimated value  $V_0(k)$  from the following equation (25).

$$V_0(k) = \Delta V_0(k) + V_{\text{ini}} \quad \text{--- (25).}$$

[0032] At a step S90, battery controller 30 calculates the charge rate SOC( $k$ ) from open-circuit 10 voltage  $V_0(k)$  calculated at step S80 using a correlation map of the open-circuit voltage versus the charge rate as shown in Fig. 4. It is noted that, in Fig. 4,  $V_L$  denotes the open-circuit voltage corresponding to SOC = 0 % and  $V_H$  denotes the open-15 circuit voltage corresponding to SOC = 100 %. At a step S100, battery controller 30 stores the necessary numerical values needed in the subsequent calculation and the present routine is ended. As described above, an operation of the apparatus for estimating the 20 charge rate of the secondary cell has been described.

[0033] (1) As described above, a relationship from among current  $I$  of the secondary cell and terminal voltage  $V$  thereof, and the open-circuit voltage  $V_0$  is structured in transfer function that as 25 in the general equation (1), that in the preferred embodiment, equation (7) (= equation (6)). Hence, it is made possible to apply an adaptive digital filter such as a least square method (well known estimation algorithm). Consequently, it becomes possible to 30 estimate parameters in equations (viz., open-circuit voltage  $V_0$  which is an offset term and poly-nominal equations  $A(s)$ ,  $B(s)$ , and  $C(s)$ ) in a form of a batch processing. These parameters are largely affected by

the charge rate, a surrounding temperature, and a deterioration and varied instantaneously. It is possible to sequentially estimate the adaptive digital filter with good accuracy. Then, if a unique  
5 correlation between the open-circuit voltage  $V_0$  and the charge rate as shown in Fig. 4 are stored, the estimated open-circuit voltage can be converted to the charge rate. Hence, it is possible to sequentially estimate the charge rate in the same way  
10 as the parameters described above.

[0034] (2) In a case where the equation (1) which is the relationship equation of current I and terminal voltage V of the secondary cell is approximated to equation (4), the equation such that  
15 no offset term is included (viz., the open-circuit voltage  $V_0$ ), a product-and-addition equation between a measurable current I which is filter processed and a terminal voltage V which is filter processed and unknown parameter (coefficient parameters of poly-  
20 nominal equations  $A(s)$ ,  $B(s)$ , and  $C(s)$  and  $h$ ) is obtained. A normally available adaptive digital filter (the least mean square method and well known parameter estimation algorithm) can directly be applied in a continuous time series.

25 [0035] As a result of this, the unknown parameters can be estimated in the batch processing manner and the estimated parameter  $h$  is substituted into equation (2), the estimated value of open-circuit voltage  $V_0$  can easily be calculated. All of these  
30 parameters are varied instantaneously, the adaptive digital filter can serve to estimate the charge rate at any time with a high accuracy. Since a constant relationship between open-circuit voltage  $V_0$  and the

charge rate (SOC) is established as shown in Fig. 4, if this relationship is previously stored, the charge rate (SOC) can be estimated from the estimated value of open-circuit voltage  $V_0$ .

5 [0036] Figs. 6A through 6I integrally shows signal timing charts with current I and terminal voltage V inputted into adaptive digital filter and representing results of simulation graphs when each parameter is estimated. As far as a time constant of  
10 a first order delay in equation (6) is concerned,  $T_1 < T_0$ . Since all parameters a through f (refer to equation (11)) are favorably estimated, the estimated value of open-circuit voltage  $V_0$  can be said to be well coincident with a real value.

15 [0037] It is noted that, in Fig. 6C which indicates the open-circuit voltage, a reason that a right side second term of equation (6) is described is to indicate that the open-circuit voltage estimated value is coincident with a real value  
20 almost without delay in spite of the fact that a late term of time constant  $T_3$  is measured on the terminal voltage inputted into the adaptive filter. In details, since the parameter estimation with the cell model formatted adaptive digital filter in  
25 equation (6), all of parameters a through f can favorably be estimated and the estimated value of open-circuit voltage  $V_0$  is well coincident with a real value.

[0038] (3) In addition, as described in item (2),  
30 in the structure in which the open-circuit voltage  $V_0$  is calculated from equation (2), the integration occurs before a value at which estimated value h is converged to the real value, its error cannot be

eliminated. However, in the structure in which equation (5) in which the integration is not included, the error before the parameter estimated value is converged into the real value does not give an  
5 influence after the convergence.

[0039] It will be appreciated that, in part of ① in Fig. 6I, before estimated value f is converged into a real value, an erroneous estimation is carried out only at momentarily. In equation (2), this value  
10 is also integrated so that the error is not eliminated. However, the error is not eliminated since even this value is integrated. However, in the structure using equation (5), open-circuit voltage  $V_0$  is calculated from the equation in which the  
15 integration is not included. Hence, after the parameter estimated value is converged into the real time, this erroneous estimation portion is eliminated.

[0040] (4) Furthermore, in a case where equation (6) is used in place of equation (1), a calculation  
20 time and program capacity can be suppressed to a minimum while having the above-described advantages.

[0040]-[0041] The entire contents of a Japanese Patent Application No. 2002-340803 (filed in Japan on November 25, 2002) are herein incorporated by  
25 reference. The scope of the invention is defined with reference to the following claims.